Regional Earthquake Likelihood Models (RELM)

- Collaboration between Southern California Earthquake Center (SCEC) and USGS
- To produce suite of credible source models for southern California
  - Test assumptions about earthquake nucleation and termination
  - Explore range of uncertainty in hazard and risk

Some assumptions to test

- Magnitude limited by fault length
- b-value varies spatially
- Earthquake probability increases with time since “last earthquake”
- Earthquake probability depends on estimate of Coulomb stress
  - Dislocation model of big quakes
  - Isotropic model based on smaller quakes

RELM agreements 2001

- $m \geq 5$
- 5 year test period with annual review
- $32 \leq lat \leq 37$, $-122 < lon \leq -114$
- 0.05 deg grid
- 0.1 deg magnitude bins
- Characterize earthquakes by mw, hypocenter

SOUTHERN CALIFORNIA EARTHQUAKE CENTER
SCEC

RELMTEST Agreements 2003

- Forecast = vector of rates: quakes per year (or day) in bins of lat, lon, mag, orientation.
- Forecasters provide numbers, not programs
- All quakes count: no distinction between foreshocks, main shocks, and aftershocks.
- Bins of 0.05 deg *0.05 deg * 0.1 mag
- Two main “menu items:”
  - Five year forecast of m>5, no updates
  - Five year forecast of m>4, updated daily
- Special orders ok if there are multiple models, and sufficient earthquakes for test

SOUTHERN CALIFORNIA EARTHQUAKE CENTER

RELM Papers, SRL 07

Petersen, Cao, Campbell, & Frankel	Time-independent and Time-dependent Seismic Hazard Assessment for the State of California
Gerstenberger, Jones, and Wiemer	Short-Term Aftershock Probabilities: Case Studies in California
Ward	Methods for evaluating earthquake potential and likelihood in and around California
Wiemer & Schorlemmer	ALM: An Asperity-based Likelihood Model for California
Helmstetter, Kagan, & Jackson	High-resolution time-independent forecast for M 5 earthquakes in California
Kagan, Jackson, & Rong	A Testable Five Year Forecast of Moderate and Large Earthquakes in Southern California Based on Smoothed Seismicity
Shen, Jackson, & Kagan	Implications of Geodetic Strain Rate for Future Earthquakes, With a Five-Year Forecast of M5 Earthquakes in Southern California
Bird & Liu	Seismic hazard inferred from tectonics: California

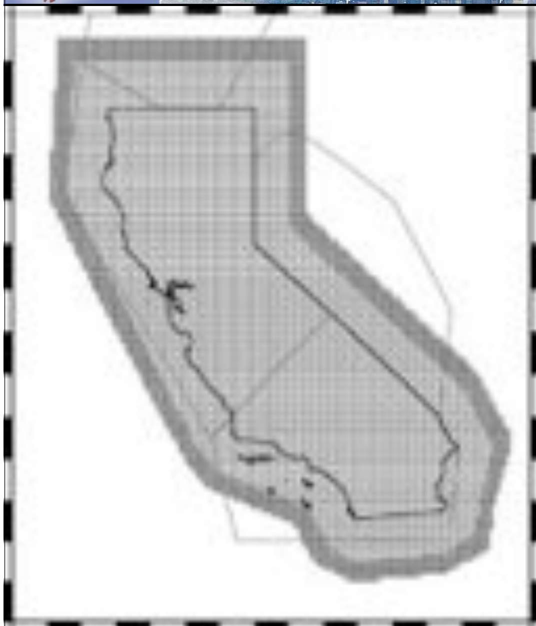
16 Oct 06 NEHRP 5

SOUTHERN CALIFORNIA EARTHQUAKE CENTER

RELM Papers, SRL 07

Holliday, Chen, Tiampo, Rundle, Turcotte, & Donnelan	A RELM earthquake forecast based on pattern informatics
Ebel, Chambers, Kafka, and Baglivo	Non-Poissonian Earthquake Clustering and the Hidden Markov Model as Bases for Earthquake Forecasting in California
Rhoades	Application of the EEPAS Model to Forecasting Earthquakes of Moderate Magnitude in Southern California
Console, Murru, Catalli, and Falcone	Real time forecasts through an earthquake clustering model constrained by the rate-and-state constitutive law: Comparison with a purely stochastic ETAS model
Field et al.	Overview Paper
Schorlemmer, Gerstenberger, Wiemer, & Jackson	Earthquake Likelihood Model Testing
Schorlemmer & Gerstenberger	RELM Testing Center

16 Oct 06 NEHRP 6

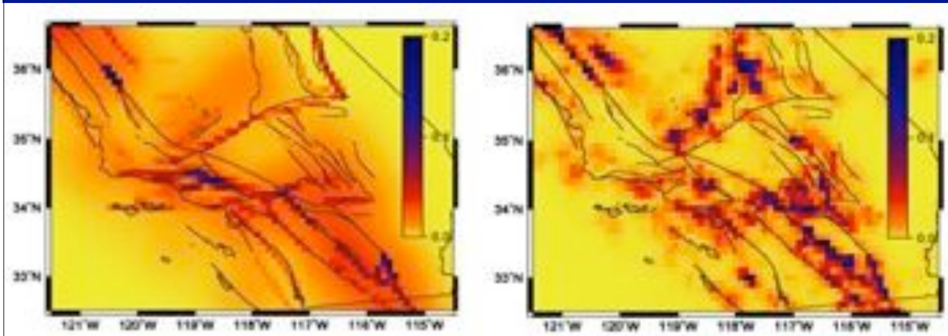


Grid for reporting RELM models: yearly rate of events for each 0.1 magnitude bin reported for 0.1 deg box centered at each grid point.

Alternative 20 year forecasts, m5.5 +

1996 NSHMP Source model, faults, characteristic eqs, smoothed seismicity.

Helmstetter et al., 2006, Smoothed seismicity m2+

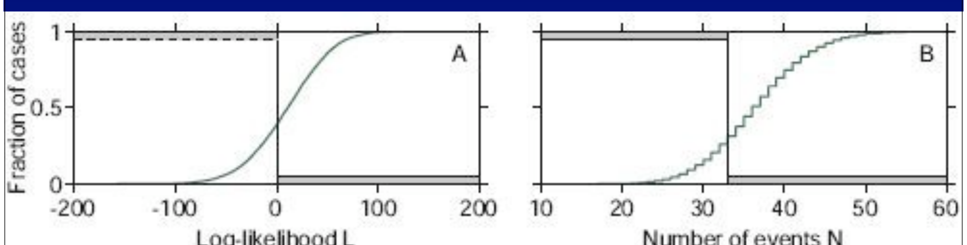


Likelihood test

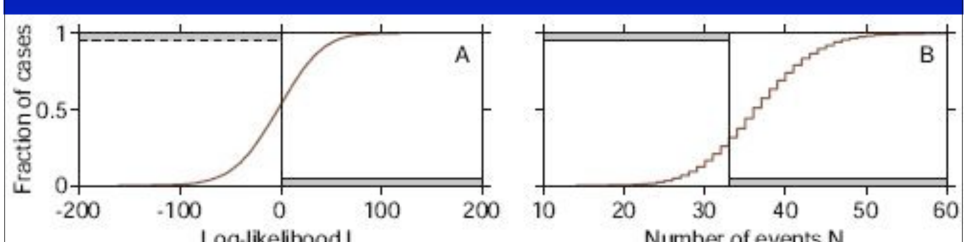
			Forecast							
					Prob					
			Ann.	Expec.						
Cell	Region	Mag range	**Rate**	5 yr	0	1	2	3	4 etc
1	1	4.95 - 5.95	**0.40**	2.0	0.14	0.27	0.27	0.18	0.09
2	1	5.95 - 6.95	**0.04**	0.2	0.82	0.16	0.02	0.00	0.00
3	2	4.95 - 5.95	**0.20**	1.0	0.37	0.37	0.18	0.06	0.02
4	2	5.95 - 6.95	**0.02**	0.1	0.90	0.09	0.00	0.00	0.00

Likelihood = log(0.18 * 0.82 * 0.37 * 0.90)

1996 NSHMP, mainshocks only, 1981 – 2000



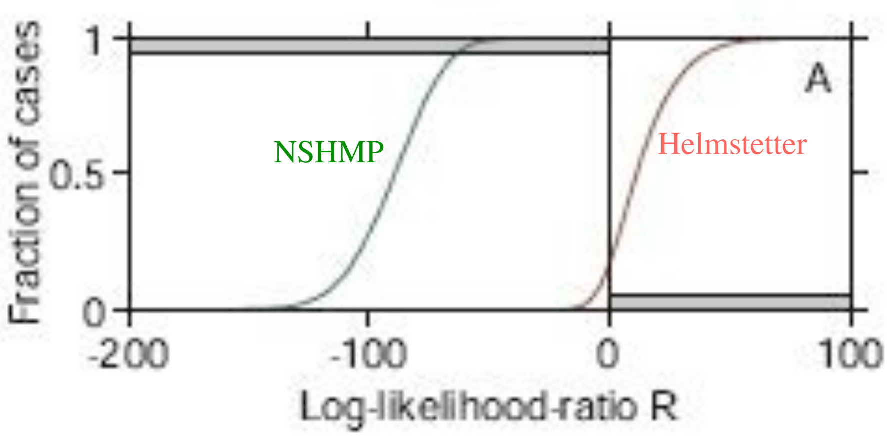
Helmstetter et al., 2006, mainshocks only, 1981 - 2000



Double Log Likelihood Ratio

- R = (L2-L02)-(L1-L01)
  - L1=Log likelihood score for hypothetical catalog, evaluated using hypothesis 1
  - L01 = Log likelihood score for observed catalog, evaluated using hypothesis 2
  - R=0 if hypothetical catalog is observed catalog

Likelihood Ratio Test, Helmstetter et al. 06/ NSHMP 96 mainshocks only 1981 - 2000



SOUTHERN CALIFORNIA EARTHQUAKE CENTER

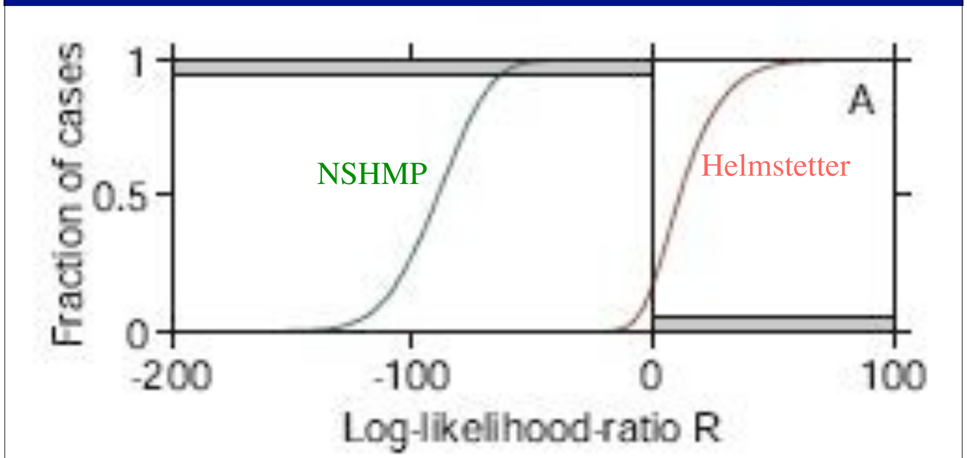
How to interpret SS curves

- Compare two models with equal prior status: each is “null hyhpothesis” for the other
- Plotted so that data favoring H2 are to right, those favoring H1 are to left
- ∀ α is probability that H1 could look more favorable to H2 than actual data; if α is less than 0.05, reject H1
- ∀ β is probability that H2 could look less favorable to H2 than actual data; if β is less than 0.05, reject H2
- Reversibility: swapping H1 and H2 swaps α and β. That is $\alpha 12 = \beta 21$

16 Oct 06 NEHRP 13

SOUTHERN CALIFORNIA EARTHQUAKE CENTER

Likelihood Ratio Test, Helmstetter et al. 06/ NSHMP 96 mainshocks only 1981 - 2000



16 Oct 06 NEHRP 14

SOUTHERN CALIFORNIA EARTHQUAKE CENTER

Conclusions and comments

- Testing is possible but not easy
  - Many investigators willing to go for it
  - Requires fairly detailed rules
  - Requires compromises (e.g., point sources)
  - All possible quakes must be assigned probability in advance
- Clustering causes big problems
  - Present tests assume Poisson behavior
  - Conditional probabilities change during experiment, requiring simulation of all possible outcomes
- Example favors smoothed seismicity over fault based model,
  - But retrospective test unfair
  - Fault-based model (NSHMP 96) not optimized for Likelihood test